NOAA's Tide Gauge Network

Tide Station Operation and Sea Level Analysis

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1. Project Summary

The National Oceanic and Atmospheric Administration (NOAA) Center for Operational Oceanographic Products and Services (CO-OPS) operates and maintains a network of 210 long-term, continuously operating coastal water level stations on all U.S. coasts and in the Great Lakes. This National Water Level Observation Network (NWLON) also includes stations on Pacific and Caribbean ocean islands, U.S. territories, and possessions. Many of these stations have now been in operation for over 100 years, with a few having been in operation for over 150 years. NOAA, through CO-OPS, has the national legal authority for coastal tides, tidal currents, and water levels, and is the U.S. leader on relative sea level information for all parts of the U.S. The operation of these stations, and their long period of record, is critical to understanding sea level rise and climate variability, both on a global and local scale. Tide gauge records provide relative sea level trends critical for coastal zone management, engineering, and long-term planning and decision-making on a local and national scale. They also provide calibration for satellite altimeters to better understand and measure global sea level changes caused by thermal expansion and changes in freshwater input. While the period of record for satellite altimeters is relatively short, tide gauge records exist for several decades, giving us a better understanding of what changes we have seen, and how that reflects future variability in sea level due to climate change. All NWLON stations are multi-purpose, providing both long-term and real-time water level information to support multiple user communities, including navigation, hazard warning and mitigation, and coastal zone management. In the climate community alone, immediate users of this data include climate researchers, NOAA and federal partners who use the information to develop climate mitigation strategies for coastal communities or for management decisions, coastal managers responsible for implementing climate change response and mitigation strategies, the general public, climate modelers requiring local information to downscale global models and develop local projections, and many others. All CO-OPS data are available real-time, and products, including long-term trends and monthly and annual means, are available through the CO-OPS *Sea Levels Online* web site, and are archived at all three Global Sea Level Observing System (GLOSS) archive centers. The data are also available through the Permanent Service for Mean Sea Level. Twenty-seven NWLON stations currently comprise the U.S. contribution to the GLOSS Core Network, and forty-five are part of the GLOSS-Long Term Trend (LTT) network. CO-OPS also supports the Global Earth Observation System of Systems (GEOSS) by providing on-line sea level trends and analysis for 114 international GLOSS-LTT stations by operating and maintaining the GLOSS-ALT tide gauges at Oil Platform Harvest for satellite altimeter calibration and evaluation, and by maintaining the long-term tide station at Bermuda. These efforts directly support the NOAA Climate Program Office (CPO) deliverable with respect to sea level: to identify changes resulting from trends and variability in climate. Failure to continue operation of CO-OPS' observing systems, update long-term time series, and analyze sea level trends on a national and global scale would cause a large gap in the Global Ocean Observing System for Climate and negatively impact understanding of both local and global sea level changes as an indicator of climate change. Additionally, local sea level trend information is being used more frequently by coastal planners and decision makers as policy is beginning to reflect better climate science. Hindering access to that information through lack of support for *Sea Levels Online* and associated products would force managers to go back to making generalizations, often at the expense and risk of the general public through poor planning.

2. Scientific and Observing System Accomplishments

Accomplishments by CO-OPS in the area of climate variability can be divided into three primary tasks, as outlined in the 2011 work plan delivered by CO-OPS to CPO in December 2010. 2011 work was primarily a continuation of the work begun in previous years, with some added benefit to CPO and the climate community through increased emphasis on global sea level analysis and GPS on Tide Stations, now a major GLOSS recommendation. All three tasks directly support the Climate Program Office's sea level deliverable, to identify changes resulting from trends and variability in climate. These tasks are:

- Operate and Maintain Water Level Measurement Systems on Platform Harvest (in support of calibration of the TOPEX/Poseidon and Jason-1 satellite altimeter missions).

- Upgrade NWLON Stations and Enhance Tidal-Geodetic Connections and Co-location of Continuous GPS at Tide Stations

- Support and Expand Global Sea Level Analysis

It should be noted that work continued on a previously identified task (FY10 work plan) for which CO-OPS did not request funding in FY11, but which provides a valuable contribution to the climate community. This task will also be reported on:

- Sea Level Quality Control and Metadata Validation

2.1 Satellite Altimetry Support (Platform Harvest)

Support for the TOPEX/Poseidon satellite altimeter mission began with installation of an acoustic system and a digibub system on Platform Harvest in 1992 (see Figure 1a). System operations include provision of water level measurements relative to the satellite altimeter closure analysis reference frame for calibration monitoring (see B. Hanes et al, Special Issue of Marine Geodesy, 2003 "The Harvest Experiment: Monitoring Jason-1 and TOPEX-Poseidon from a California Offshore Platform"). CO-OPS' special support for this site has included a vertical survey on the Platform necessary to relate the water level sensor reference zeros (near the bottom catwalk) to the GPS reference zero (located up top at the helipad on the Platform). Continuous data are required to monitor effects of waves on the water level measurements and to ensure provision of data during the times of altimeter over flights every ten days, so care is taken to ensure accurate and reliable data collection and dissemination. Raw and verified 6-minute interval water level data are posted on the CO-OPS web-site.

Figures 1a-b (from left). 1a. Platform Harvest Calibration Site at which NOAA tide gauges are located. 1b. Leveling Point for one of the pressure sensors.

The original acoustic system was replaced by a digibub pressure system prior to the Jason-1 altimeter launch. These two digibub pressure tide gauge systems have been collecting continuous water level data streams surveyed into the Platform and Satellite Orbit Reference frames. In 2009, CO-OPS replaced one of the two nitrogen tanks and digibub systems with an air pump, which is a safer, more reliable, and more cost-effective system for long-term maintenance. Both systems were not replaced at once in order to ensure continuous operation and monitor the success of the air pump at this site prior to a full replacement. In August 2010, the second nitrogen tank system was replaced with an air pump system by NOAA/CO-OPS' Pacific Regional field Office (PRO). The replacement of the nitrogen tanks with air pumps ensures a more continuous, uninterrupted supply of pressure to the paros pressure sensors. This new system is easier to maintain, safer, and more cost effective.

Work at the station in 2011 focused on exploring enhanced communication, repairs, and removal of nitrogen tanks following successful replacement with the air pump systems (they had been left in place while performance of the new systems was monitored). Additional maintenance work done at Platform Harvest included routine maintenance, digital precision levels between both sensors and the primary benchmark (Figure 1b), and replacement of the GOES antennas for the DCPs. Additional mechanisms for communication were explored. The team was unsuccessful in getting a local LAN line for phone access at the site, and were unable to get a wireless signal, severely limiting the potential for redundant communications. This will continue to be explored in the future; Iridium may prove to be the best source of redundant communication to ensure continuous and timely data access. The GOES antennas were inspected and it was determined that they did not need to be replaced as had been expected due to the damage incurred when the brackets upon which they were mounted were torn off. The mount was replaced (Figure 1c), and the GOES antennas will be used for this station in the future. The orifices were inspected and remain in good condition.

Figure 1c. Replaced GOES antenna mount.

Annual CPO funding is used to cover travel to and routine emergency maintenance of this site, as well as and water level and ancillary sensor calibrations. Without this funding, this site could not be maintained. This site is critical for calibration of the satellite altimeters for global sea level observation and measurement. Annual inspections and maintenance and annual levels are necessary to maintain the station, both in operation and in the verification of stability. The replacement of air pump systems was important to increase the reliability of the sea level data and minimize disruptions to the time series. Additionally, this change increases the safety and decreases the cost of maintenance. Exploration of enhancements to communication will continue, as reliable telemetry to the site is important, both for trouble-shooting of issues in station operation and maintenance of a continuous time series.

In summary of FY11 accomplishments, the identified task was:

- Operate and Maintain Water Level Measurement Systems at Platform Harvest

The identified deliverables were:

Deliverable a: Complete Annual Inspection and routine maintenance at Platform Harvest.
Deliverable b: Perform annual levels to bench marks on the oil platform from the water level sensors.
Deliverable c: Establish level connection to GPS sensors.
Deliverable d: Explore requirements for enhancement of communications to Platform Harvest for real-time data dissemination. (Continued from FY10)
Deliverable e: Replace GOES antennas.

Deliverables a-c were fulfilled in entirety. Deliverable d continues to be underway, and will continue over the coming year. Deliverable e was determined not to be necessary, but the necessary replacement was completed and provision was made for the work in future years at no additional cost through purchasing of equipment. All five deliverables are critical to support CPO's sea level deliverable.

2.2 Tide Station Upgrades and Geodetic Connections

There are several coastal and island NWLON stations critical to the Global Ocean Observing System for Climate. The operation and maintenance of the ocean island stations of the National Water Level Observation Network (NWLON) has been increasingly more difficult over time due to the slow abandonment of the island facilities by the U.S. Department of Defense, at which some of the stations reside. Finding routine and/or cost-effective flights can be difficult, yet these stations require high standards of annual maintenance to ensure the integrity of their long term data sets. Annual maintenance is extremely important, especially in light of the fact that corrective maintenance is logistically very difficult and expensive. Therefore, over the past few years, a portion of the CO-OPS contribution to the NOAA Climate Program Office has been to upgrade hardware and software at 11 identified critical ocean island sites, creating redundancy in data collection to ensure continuous time series, improving communications where necessary, and establishing geodetic connections and continuous GPS monitoring sites where they did not previously exist. Establishing a geodetic connection, and monitoring rates of land motion at sea level observation points is critical in understanding the mechanisms contributing to local rates sea level rise and better quantifying rates of global change. All of this work supports the CPO deliverable to identify changes resulting from trends and variability in climate. Observations are critical to this sea level work. Upon completion of the work in 2011, this priority task is now nearly complete (see Table 1).

To date, the only additional outstanding task in this original set of priority upgrades is completing the upgrade of the Adak tide station through installation of redundant data collection platforms (DCPs). Equipment has been purchased to installed redundant data collection platforms in Adak, Alaska in order to provide redundancy at this remote location, and the work was planned for FY11. However, the pier upon which the tide station is located has been condemned and the station will have to be relocated. A reconnaissance was completed, and the additional DCPs will be added to the station upon its relocation.

CO-OPS worked with the National Geodetic Survey, who worked with a partner agency, in FY10 to establish a geodetic connection at the Midway tide station (through static GPS observations). Unfortunately, following observation it was revealed that there was a problem with the data. This observation was completed again in FY11 at no additional cost to CPO to establish a solid geodetic connection. This task is now complete.

The challenges that have been encountered while implementing upgrades and improvements underscore the importance of doing such work. These sites are among the most critical sites in the U.S. for sea level observation, and in order to ensure a continuous sea level time series, redundancy is critical.

Table 1. Status of Ocean Island NWLON Station Upgrades and Improvements

Station	Upgraded	Geodetic Connection	CORS Operating
Guam	Yes	Yes	Yes
Kwajalein	Yes	Yes	Yes
Pago Pago	Yes	Yes	Yes
Wake Island	Yes	Yes	No**
Midway	Yes	Yes	No**
Adak	No*	Yes	Yes
Bermuda	Yes	Yes	Yes
San Juan, PR	Yes	Yes	Yes
Magueyes Island, PR	Yes	Yes	Yes
Charlotte Amalie, VI	Yes	Yes	Yes
St. Croix, VI	Yes	Yes	Yes

* Will be completed in FY12 without additional funding requested
** Will be included in the FY12 work plan and should require minimal additional funding

In 2011, work on this task primarily focused on the co-location of Continuously Operating Reference Stations (CORS) on NWLON tide stations, which was the most substantial remaining task. Three CORS installations were planned for FY10: Midway, Wake Island, and San Francisco, California. Midway's installation was a carry-over from the FY09 work plan, and did not utilize FY10 CPO funding. 2010 CPO funding was intended to be used for the Wake Island and San Francisco CORS. The completion of CORS installations at Midway and Wake Island will complete the tasks originally identified for ocean island stations. However, in light of the increased global focus on co-location of continuous GPS measurements at long-term tide stations for climate observation, and the new GLOSS requirement to include a continuous GPS sensor at all GLOSS stations, CO-OPS began focusing on additional gaps in co-located CORS/NWLON coverage beyond the initial 11 sites. San Francisco was selected as the first candidate for co-located CORS in the contiguous U.S. because of the lack of co-located sites on the West Coast, the fact that San Francisco is the longest continuously operating sea level station in the U.S., and because it is also a GLOSS station, making it a high priority for global and local sea level observation. FY10 funding was received late in the fiscal year, and therefore planning, permitting, and contracting began very late in the year and was carried into FY11. The contract was put out for bid (and a vendor selected) before the end of FY10. However, upon reconnaissance of the sites at Midway and Wake Island, there were immediate obstacles and additional costs that came up. The decision was made midway through FY11 to focus on the additional West Coast sites included in the FY11 work plan while these issues were resolved, in order to install as many CORS as possible this FY. The FY11 work plan included two additional CORS sites at La Jolla, California and South Beach, Oregon. (*Note: upon additional conversation with CPO during FY11, the requirement for La Jolla, CA was shifted to Crescent City, CA.*)

In order to ensure maximum cost efficiency, installation of these three CORS sites was included in a larger contract executed by the National Geodetic Survey. Additional sites will be handled similarly, though through a new contract.

CO-OPS, in partnership with NGS, worked in FY11 on three CORS sites: San Francisco, Crescent City, and South Beach. Permitting and ground work continues for Midway and Wake Island though the actual installation will be handled through a new contract using carryover funds. It has been determined that the lead time for additional CORS at NWLON stations is at least 18 months. Future work plans will reflect this lead time. All funding received to date by CPO has gone and will continue to go to the installations as outlined in previous work plans. A detailed summary of each location and its status is as follows:

San Francisco, CA

Most of the area surrounding the NOAA tide-gauge in San Francisco is owned by the Presidio and much of the land is either open to the public or subject to strict construction restrictions. The NGS contractor met with Presidio staff and 3 possible locations were identified and requests for architectural plans and long-term viability were obtained. After a few months all three locations were dismissed either due to Presidio decision or planned demolition of the buildings within 5 years. Another building was identified and approved for a roof top mount, but again had to be withdrawn as Presidio recognized that it too was scheduled for demolition. An alternate location was identified in late August, but Presidio approval remained positive, but not definitive and was ultimately withdrawn just days before the installation was to begin. In December of 2011 an additional recon and meeting with the Presidio was held and a new location was identified and permitting for this location has begun. Presidio anticipates 3-4 months for permitting to be completed. Installation should require less than 1 week of work.

Wake Island, Pacific Ocean

Initial coordination with the US Air Force (USAF) indicated that site construction would be able to begin in May-June of 2011. However in late March USAF identified that the MOU between USAF and NOAA had expired, several years earlier, and they would not permit construction till this was renewed/reestablished. The expired MOU was between NOAA-NWS and USAF. NOAA-COOPS began work on establishing a new MOU, but given the protracted nature of establishing MOUs, NGS and CO-OPS decided to find an alternate construction location which was Crescent City, CA. This refocus was discussed with CPO.

Crescent City CA

The CORS was quickly built in September of 2011. The CORS is located on the pier adjacent to the tide-gauge. An alternate location near some of the reference tide-gauge marks was not possible. Data has been flowing from this site since October 2011 to the NGS CORS Network online storage.

Figure 3. GPS antenna at Crescent City.

Midway Island, Pacific Ocean

A CORS location was selected not only with the proximity to the existing NOAA tide-gauge, but especially to minimize its environmental impact as Midway is part of the Papahānaumokuākea

Marine National Monument and is environmentally very sensitive. The proposed location was identified by University of Hawaii Sea Level Center (UHSLC) staff with FWS preliminary approval a number of years ago, but never finalized. The selected site was on an existing well casing established by the Incorporated Research Institute for Siesmology (IRIS) and the Nuclear Test-Ban Treaty Organization. The seismologists agreed to permit NOAA to use the well head as the base of GPS antenna, as they are not using it, and also offered to use their existing buried conduit to take the antenna cables into their building where the GPS receiver could be housed, and provide internet access. After securing the seismologists approval and having obtained approval in principle from FWS we proceeded ahead with final approval from FWS and planning for installation. In April FWS indicated that approval was not likely without a full scale environmental assessment, which would take several months, followed by a formal permitting application and possible recurring charges. Again NGS and COOPS decided to find an alternate location and selected South Beach, OR. This refocus was also discussed with CPO in June 2011.

South Beach, OR

The site was visited twice by an NGS state advisor who consulted with onsite owners in particular the NOAA facility and Port of Newport and after additional discussion a warehouse roof was identified and approved. The contractor arrived on site and attached the mast to the roof and the following day was told to suspend all additional work, due to concerns on the roof membrane warranty. No fault was found with the contractor, but protracted negotiations followed, between NOAA-NGS and the Port of Newport, who own the building, to ensure that some retrofitting of the mast mounting would be done to allow remove any voiding of roof membrane warranty. An agreement was established in late December 2011 and final work is planned for February/March of this year.

In summary, in October 2010 CO-OPS provided funds for NGS to construct 3 CORS at tide-gauge sites. The 3 selected locations were San Francisco, CA, and the Pacific Islands of Midway and Wake. Modifications to the contract were necessary, and the three selected locations were then San Francisco, Crescent City, and South Beach OR. Shortly after, the contract mechanism that NGS used for installation of the CORS was no longer available. A new contract is under development. The additional funding received by CO-OPS in FY11 will be given to NGS in FY12 to continue work on Midway Island and Wake Island. If applicable, any additional expenses to be incurred for these stations in light of the permitting and environmental impact issues that have arisen will be included in the FY12 work plan, and CO-OPS will discuss with CPO whether to proceed or utilize these funds for alternate sites. CPO has expressed that Midway and Wake Island remain priorities. The FY12 work plan will also feature a 5-year plan for installation of CORS at all remaining US GLOSS stations within the NWLON.

In summary of FY11 accomplishments, the identified task was:

- Upgrade NWLON Stations and Enhance Tidal-Geodetic Connections and Co-location of Continuous GPS at Tide Stations

The identified deliverables were:

Deliverable a: Installation of two new data collection platforms will be performed in FY11 at Adak, Alaska. (Continued from FY10)
Deliverable b: A geodetic connection at Midway through GPS will be completed in FY11. (Continued from FY10)
Deliverable c: Installation of a CORS station at Midway Island, within 1 km of the tide station. (Continued from FY10)
Deliverable d: Installation of a CORS station at Wake Island, within 1 km of the tide station. (Continued from FY10)
Deliverable e: Installation of a CORS station at San Francisco Bay, within 1 km of the tide station. (Continued from FY10)
Deliverable f: Installation of a CORS station at La Jolla, California, within 1 km of the tide station (subject to modification following site reconnaissance and further discussion with OCO)
Deliverable g: of a CORS station at South Beach, Oregon, within 1 km of the tide station (subject to modification following site reconnaissance and further discussion with OCO)

Deliverable b was completed. Deliverable f was also completed, though the station location was changed from La Jolla to Crescent City. Deliverable a will be completed upon relocation of the station to a more stable structure. Deliverables c and d remain underway. Deliverables e and g are nearly complete. All seven deliverables were underway in FY11 through CPO funding, and will be completed as applicable in FY12. The tasks will be reflected in the FY12 work plan.

All deliverables directly support CPO's sea level deliverable. Additionally, co-location of continuous GPS on tide stations was identified as a priority at OceanObs '09 as a global climate priority, and is highlighted in the new (draft) GLOSS Implementation Plan as a requirement for all GLOSS stations. **Beginning in FY12, the focus for this task will shift to primarily CORS on NWLON, and a 5-year plan for completing installations at all US GLOSS stations will be included.**

2.3 Annual Sea Level and Extreme Event Analysis

The 1997 International Sea Level Workshop Report identified 62 water level stations as a core global subset for long-term trends, referred to by the Climate Observation Program as climate "reference stations." In addition to these 62 reference stations, 182 global tide stations were identified in Annex IV of the Global Sea Level Observing System (GLOSS) Implementation Plan (IOC Technical Series No. 50) (http://unesdoc.unesco.org/images/0011/001126/112650eo.pdf) as GLOSS-LTT (Long-term trend) stations. 45 of the GLOSS-LTT stations are CO-OPS stations and their sea level trends have been available on *Sea Levels Online* for several years. However, beginning in 2008, GLOSS Long-Term Trend (GLOSS-LTT) stations were analyzed in addition to the initial reference network, and their trends included online. While the 2010 GCOS implementation plan places a lesser emphasis on the LTT stations, they were the original focus of the expanded global sea level trends. That work has been completed.

In FY2011, CPO funding was used to expand the Global Sea Level Trends section of *Sea Levels Online.* The product suite now includes 9 new countries, expanded the limited geographic coverage of 11 countries, for a total of 165 global stations (Figure 4). This is almost double the number of trends previously calculated and includes coverage of 59 countries worldwide. These efforts directly support the NOAA Climate Program Office deliverable with respect to sea level: the expanded number of stations will help capture the variability in relative sea level change internationally, and contribute to global sea level rise estimates. Furthermore, 70 historical stations were updated with new data since 2005 and trends were re-calculated. In the future, these updates will assist the review of sea level acceleration from climate change. In addition to rise and fall trend estimates, there are two updated products for a complete oceanographic assessment. The 'Average Seasonal Cycle' illustrates the regular fluctuations in coastal temperatures, salinities, winds, atmospheric pressures, and ocean currents, compared to the 'Interannual Variation' which delineates irregular conditions and periodic variations such as El Nino-Southern Oscillation (ENSO). Data used in the analysis is from the Permanent Service for Mean Sea Level, who is responsible for the collection, publication and annual updates of sea level data from the global network of tide gauges. These products also support the Global Sea Level Observing System (GLOSS), an international program under the World Meteorological Organization (WMO) and the Intergovernmental Oceanographic Commission (IOC). The products can be found here: http://www.tidesandcurrents.noaa.gov/sltrends/index.shtml. This website provides a critical service to the GLOSS community as well as to the coastal decision maker who needs to understand what changes are occurring locally.

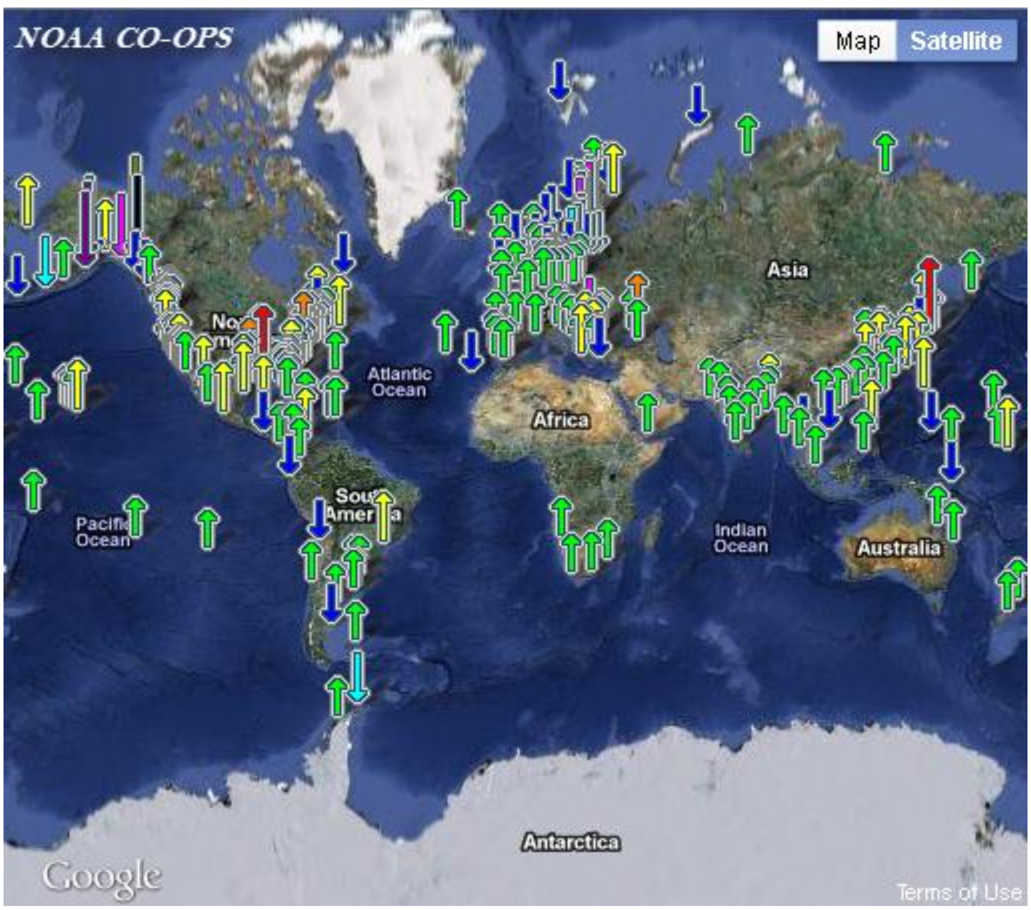


Figure 4. Global sea level stations with long-term trends available on *Sea Levels Online.*

Table 2. Stations available under the Global Sea Level Trends Section of *Sea Levels Online*.

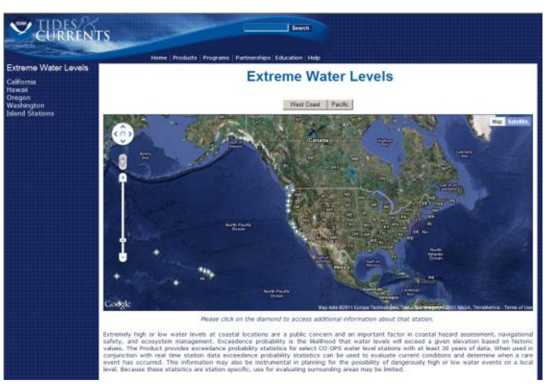
Reykjavik, Iceland	Korsor, Denmark	Durban, South Africa	Tonoura/Hamada, Japan
Torshavn, Denmark	Slipshavn, Denmark	Aden, Yemen	Toyama, Japan
Barentsburg , Norway	Fredericia, Denmark	Karachi, Pakistan	Wajima, Japan
Russkaya Gavan II, Russia	Aarhus, Denmark	Kandla, India	Chichijima, Japan
Murmansk, Russia	Hirtshals, Denmark	Mumbai/Bombay, India	Legaspi, Philippines
Dikson, Russia	Esbjerg, Denmark	Marmagao, India	Jolo, Philippines
Tiksi, Russia	Cuxhaven 2, Germany	Cochin, India	Rabaul, Papua New Guinea
Providenia, Russia	Oostende, Belgium	Chennai/Madras, India	Townsville , Australia
Vardo, Norway	Lerwick, UK	Vishakhapatnam, India	Bundaberg, Australia
Honningsvag, Norway	North Shields, UK	Paradip, India	Wellington, New Zealand
Narvik, Norway	Newlyn, UK	Gangra, India	Lyttelton II, New Zealand
Rorvik, Norway	Stornoway, UK	Haldia, India	Majuro B/C, Marshall Islands
Heimsjo, Norway	Malin Head, Ireland	Diamond Harbour, India	Rikitea, France
Maloy, Norway	Dublin, Ireland	Port Blair, India	Easter Island E, Chile
Bergen, Norway	Socoa, France	Ko Taphao Noi, Thailand	Prince Rupert, Canada
Stavanger, Norway	La Coruna , Spain	Raffles Light House, Singapore	Vancouver, Canada
Tregde, Norway	Cascais, Portugal	Sultan Shoal, Singapore	Victoria, Canada
Smogen, Sweden	Lagos, Portugal	Ko Lak, Thailand	Tofino, Canada
Klagshamn, Sweden	Tarifa, Spain	Quinhon, Vietnam	Ensenada, Mexico
Kungholmsfort, Sweden	Malaga, Spain	Hondau, Vietnam	Cabo San Lucas, Mexico
Landsort, Sweden	Marseille, France	Macau, China	Guaymas, Mexico
Stockholm, Sweden	Trieste, Italy	Zhapo, China	Manzanillo, Mexico
Ratan, Sweden	Rovinj, Croatia	Xiamen, China	Acajutla, El Salvador
Furuogrund, Sweden	Bakar, Croatia	Kanmen, China	Quepos, Costa Rica
Kemi, Finland	Split Rt Marjana, Croatia	Lusi, China	Balboa, Panama
Oulu/Uleaborg, Finland	Split Harbour-Gradska, Croatia	Dalian, China	Buenaventura, Colombia
Raahe/Brahestad, Finland	Dubrovnik, Croatia	Quarry Bay/North Point, China	La Libertad II, Ecuador
Pietarsaari/Jakobstad, Finland	Katakolon, Greece	Tai Po Kau, Hong Kong	Antofagasta , Chile
Vaasa/Vasa, Finland	Kalamai, Greece	Tsim Bei Tsui, Hong Kong	Talcahuano, Chile
Kaskinen/Kasko, Finland	Khalkis North, Greece	Keelung II, Taiwan	Puerto Deseado, Argentina
Mantyluoto, Finland	Thessaloniki, Greece	Mokpo, South Korea	Puerto Madryn, Argentina
Turku/Abo, Finland	Kavalla, Greece	Pusan, South Korea	Quequen, Argentina
Degerby, Finland	Alexandroupolis, Greece	Ulsan, South Korea	Mar Del Plata (NB), Argentina
Hanko/Hango, Finland	Khios, Greece	Mugho, South Korea	Buenos Aires, Argentina
Helsinki, Finland	Leros, Greece	Wonsan, North Korea	Stanley I/II, UK
Hamina, Finland	Rodhos, Greece	Yuzhno Kurilsk, Russia	Montevideo, Uruguay
Liepaja, Latvia	Bourgas, Bulgaria	Petropavlovsk-Kamchatsky, Russia	Cananeia, Brazil
Kaliningrad, Russia	Varna, Bulgaria	Abashiri, Japan	Cartagena, Colombia
Gdansk/Nowy Port, Poland	Constantza, Romania	Kushiro, Japan	Cristobal, Panama
Wladyslawowo, Poland	Tuapse, Russia	Hakodate I, Japan	Progreso, Mexico
Ustka, Poland	Poti, Georgia	Wakkanai, Japan	Cabo San Antonio, Cuba
Kolobrzeg, Poland	Batumi, Georgia	Mera, Japan	Saint John, N.B., Canada
Swinoujscie, Poland	Ceuta, Spain	Aburatsubo, Japan	Halifax, Canada
Warnemunde , Germany	Ponta Delgada, Portugal	Kushimoto, Japan	Pointe-Au-Pere, Canada
Wismar, Germany	Funchal I & II, Portugal	Hosojima, Japan	Quebec, Canada

Gedser, Denmark	Walvis Bay, Namibia	Aburatsu, Japan	Neuville, Canada
Kobenhavn, Denmark	Simons Bay, South Africa	Nagasaki, Japan	Nain, Canada
Hornbaek, Denmark	Port Elizabeth, South Africa	Naha, Japan	Bahia Esperanza, Antarctica

Work was also continued on the development of an exceedance probability analysis web product for NWLON stations. The Center for Operational Oceanographic Products and Services (CO-OPS) provides exceedance probability statistics for select water level stations with at least 30 years of data through its *Extreme Water Levels* website (http://tidesandcurrents.noaa.gov/est/). In September 2011, the main website for the product was released and statistics provided for water level stations in California, Hawaii, Oregon, Washington, the Pacific Islands, and Puerto Rico on the home page of the CO-OPS under the product menu. The product will provide exceedance probability statistics on the remaining water level stations in Alaska and on the East and Gulf Coasts that meet the 30 years of data criteria by April 30, 2012.

Access to statistics for individual stations is via a Google Map Interface where users can select a station in a region of interest (Figure 5). From the pop-up menu which provides the 1% exceedance probability levels for the selected stations, users may select the Extreme Water Levels page, the Exceedance Probability Curves, or the Exceedance Probability Levels (Figure 6). This site provides access to the monthly highest and lowest water levels overlaid by the exceedance probability levels (Figure 7), exceedance probability curves relative to return periods (Figure 8), and exceedance probability levels relative to tidal datums (Figure 9).

Extremely high or low water levels at coastal locations are a public concern and an important factor in coastal hazard assessment, navigational safety, and ecosystem management. Exceedance probability is the likelihood that water levels will exceed a given elevation based on historic values. The Product provides exceedance probability statistics for select CO-OPS water level stations with at least 30 years of data. When used in conjunction with real time station data, exceedance probability statistics can be used to evaluate current conditions and determine when a rare event has occurred. This information may also be instrumental in planning for the possibility of dangerously high or low water events on a local level. Because these statistics are station specific, use for evaluating surrounding areas may be limited.



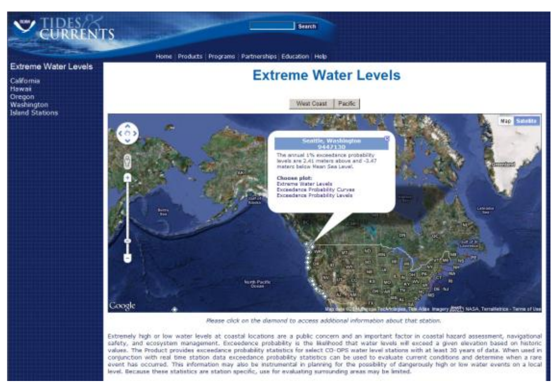
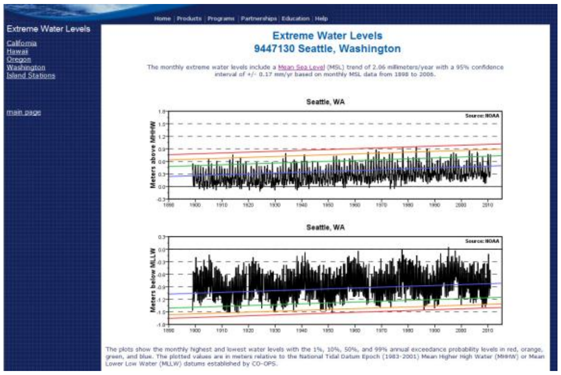


Figure 5 (left). Google Map Interface for Exceedance Probability Statistics on Extreme Water Levels
Figure 6 (right). Pop-up menu for example station Seattle 9447130 from which users can select Extreme Water Levels, Exceedance Probability Curves, or Exceedance Probability Levels.



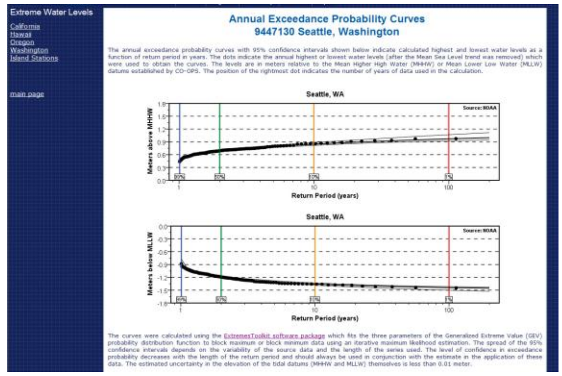


Figure 7 (left). The monthly highest and lowest water levels overlaid by the exceedance probability levels.
Figure 8 (right). Exceedance Probability Curves relative to Return Periods with 1 year, 2 years, 10 years, and 100 years identified.

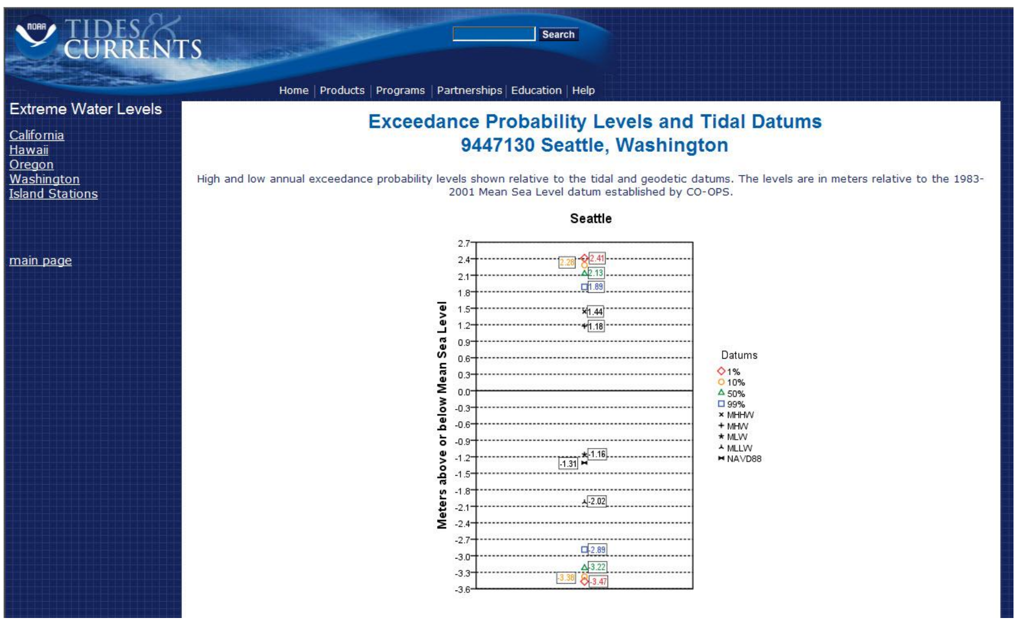


Figure 9: Exceedance probability levels relative to tidal and geodetic datums.

Finally, CO-OPS has also been working on the development of a sea level advisory product. Currently, there are no sea level advisories or bulletins that systematically report on sea level anomalies along the U.S. coast. The need for such became apparent after a severe regional sea level anomaly in June - July of 2009 when higher than normal sea levels coincided with a *perigean-spring* tide, which together produced coastal flooding, and caught the attention and concern of many coastal communities because of the lack of coastal storms that normally causes such anomalies. The Sea Level Advisory Project will add a valuable component to CO-OPS real time sea level monitoring capability. The goal will be to automatically detect the occurrence of sea level anomalies (a significant height above or below tide prediction) as well as identify regional physical forcing mechanisms from specific observation platforms (buoys and satellite) to explain probable mechanisms driving the sea level events. The anomaly thresholds will be calibrated to a locality in terms of flood-potential elevations or decreased depths important in terms of ship-grounding dangers. This is an important effort because it addresses the societal implications of climate change and sea level variability by providing a tool to help understand and mitigate the effects of sea level change on multiple time and spatial scales.

Charleston, SC was a chosen as the beta-region since this area has little remaining free board in terms of its downtown infrastructure. The National Weather Service (NWS) issues multiple flood watches every year that largely result from astronomical (earth-sun-moon system) tide forcing alone and NOAA's Coastal Services Center (CSC) often receives inquiries regarding downtown flooding during sunny, nondescript days. The number of flooding episodes has been increasingly over time, though this distinct trend has not been readily conveyed to the public (Figure 10).

Analysis in FY11 included multivariate analysis of historical daily water levels, gridded ocean winds (NOAA Blended Sea Winds), sea level pressure (NOAA/NCEP reanalysis), local sea surface temperature (SST, NOAA/CO-OPS) and Florida Current (FC)Transport (NOAA/AMOL) to identify applicable forcing responsible for the water level response at the NOAA Charleston Gauge. In addition, climotologies (frequency, magnitude and duration) of non-tidal anomalies were computed that correspond to seasonal thresholds capable of flooding. The concept is that tracking the major drivers – 1) specific regions of offshore winds, 2) autoregressive, lagged water level signal and 3) FC transport which explain around 70% of the daily water level variability – would allow for a utilization of the regional observation platforms to explain local climate-related phenomenon. Coupled with knowledge of the spring/neap cycles, a template is set that determines 'vulnerable' periods due to astronomical tide forcing and physical forcing regimes (Figure 11).

The aim of the analysis is to provide a deeper appreciation of surge-to-seasonal patterns of variability and compliment a community's living memory of sea level elevations/impacts needed to motivate societal adaptation as sea levels rise. Coordination with CSC and the NWS's local Weather Forecasting Offices (WFO) is on-going and the project will expand to other incident-prone regions once demonstration is accepted.

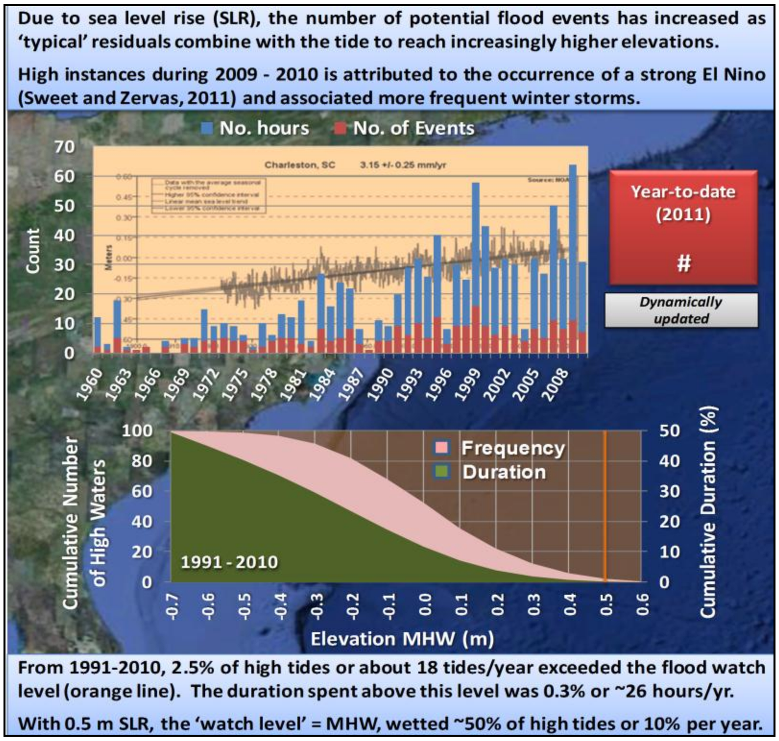


Figure 10. Illustration showing (top) increased instances that water levels have exceeded 0.5 m MHW (7 feet MLLW), a level at which the NWS issues a flood watch for Charleston due to sea level rise and (bottom) frequency and duration change associated with the flood water level with 0.5 m of sea level rise.

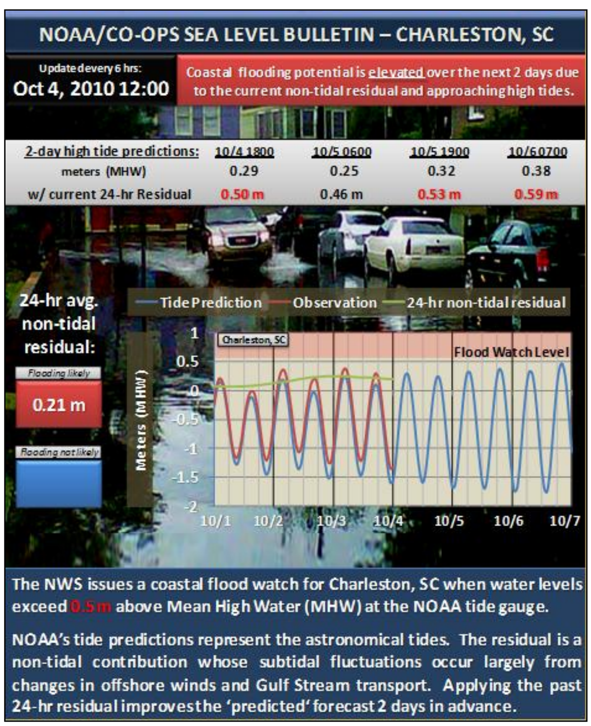


Figure 11. Schematic showing period of approaching spring tide that effectively raises the water level close to the flood watch level (0.5 MHW) on top of which a noticeable non-tidal anomaly is occurring.

In FY12, work on this product will continue. CO-OPS will continue working on the Charleston product to incorporate the concept into a user-accessible web-site that aligns with the WFO forecast and watch/warning schema. However, more in line with CPO's climate program deliverable, CO-OPS will also generate coastal sea level extreme products for seasonal outlooks within the Pacific, working jointly with the University of Hawaii Sea Level Center and NOAA/NESDIS/NCDC Pacific Regional Climate Services, which utilizes both the sea level advisory framework and the exceedance probability statistics.

In summary of FY11 accomplishments, the identified task was:

- Global sea level analysis

The identified deliverables were:

Deliverable a: 25 new stations will be added to the CO-OPS global sea level station analysis products available on *Sea Levels Online*, following common protocols and analysis methods as agreed upon with CPO in previous years. (Continued from FY10)
Deliverable b: Develop and provide access to Exceedance Probability Analysis Tool on CO-OPS website.
Deliverable c: Begin development of a CO-OPS Sea Level Advisory Product, and provide access to one pilot region in FY11.

Work on deliverable a was completed. Deliverable b was completed; however, work is underway to add additional stations to this analysis. Deliverable c had tremendous progress, and remains underway.

2.4 Sea Level Quality Control, Metadata Validation, and Data Access

From the onset of the CO-OPS sea level analysis efforts, CO-OPS has been compiling and quality controlling the data necessary to produce long term sea level trends. Despite this established process of data inventory and analysis, there are some significant historical data records that are still in non-digital form and/or require additional quality control before public distribution. In addition, some are missing ancillary and metadata information in the existing CO-OPS database structures. In FY10, to begin to address this issue, an inventory of historical data gaps and quality control issues was completed, and additional ancillary data sets that contribute to deviations or extremes in the long-term records identified. In order to begin working on compiling and verifying these data sets, the budget detailed in the FY10 work plan was to hire a contractor for six months to work through the inventory. It was late in the fiscal year by the time the funding was received and the inventory was complete, limiting contract action that could be taken. In FY11, a new CO-OPS staff person was identified to lead this effort who has prepared a statement of work and conducted interviews to hire someone to complete this work.

In 2012, through no additional CPO funding, work on compiling complete and accurate data sets, with appropriate metadata and ancillary data sets will continue, which will be made available to the public. By providing a verified long-term data set and eliminating any discrepancies in historic data, CO-OPS will help eliminate error in the utilization of the data for various climate applications. This will also increase efficiency across the climate community and minimize inaccurate or conflicting information, as currently users of CO-OPS data are often forced to analyze portions of the record themselves if they want a full, verified, sea level record. This effort supports CPO's sea level directive in understanding sea level variability by providing public access to a climate-quality sea level data record for the U.S. Though no additional funding will be requested, there will be deliverables detailing this work in the FY12 work plan.

2.5 National Water Level Observation Network Data Availability

All CO-OPS real-time and long-term water level data and sea level trends are available through several channels. Real-time water level data are available for all CO-OPS tide gauges via the internet, web services, and the Global Telecommunications System. All raw and verified data and products, standards and procedures, and data analysis reports can be accessed through http://tidesandcurrents.noaa.gov. Data can also be accessed through the IOOS web portal at http://opendap.co-ops.nos.noaa.gov/content/. Sea level products are also available online, through the CO-OPS *Sea Levels Online* web site for U.S. (http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml) and global (http://tidesandcurrents.noaa.gov/sltrends/sltrends_global.shtml) stations, as well as through the NOAA National Oceanic Data Center and others, which provide links to the CO-OPS website. Real time data are also available through the IOC Sea Level Station Monitoring Facility (http://www.ioc-sealevelmonitoring.org/) and CO-OPS works routinely with Vlaams Instituut voor de Zee to ensure data continuity and availability. Data are archived regularly in-house, and sea level data sets are provided to all GLOSS archive centers for U.S. GLOSS stations. One-minute water level data are archived weekly at the NOAA National Geophysical Data Center in Boulder, CO. CO-OPS personnel routinely verify access to the data through these channels to ensure availability. In 2011, data availability from the National Water Level Observation Network was over 96%.

2.6 Summary of Accomplishments

FY11 was a busy and successful year for CO-OPS with respect to advancing CPO's program deliverable of identifying changes resulting from trends and variability in climate. Tide gauges play a critical role in ocean observing for climate, from a broad global research perspective down to a granular local need for actionable information. The observations from the NWLON provide necessary local sea level trends for local planning and policy, enhance the understanding of global climate change, provide calibration for satellite altimeter measurement of sea level, and are an important component in the ability to downscale climate models for local projections. In FY11, we created new products, maintained and enhanced operation of critical stations, increased the coverage of paired GPS-on-tide gauge sites, and worked closely with a number of stakeholders. We were fortunate to receive level funding in FY11. If that funding support is decreased in the future, all of the work above will be at risk. Without the information and tools that CO-OPS provides, climate researchers would not have the raw data they need to understand changes in sea level, and coastal decision makers would not have that translated information available for management decisions that protect life and property.

3. Outreach and Education

NOS/CO-OPS routinely engaged in education and outreach to multiple stakeholders. In particular, there is a growing need to translate technical climate data and products (especially sea level trends) into understandable and actionable information. CO-OPS personnel works closely with coastal managers, through training and one-on-one technical guidance, to explain and provide recommendations on incorporating sea level information into policy and planning. CO-OPS personnel also play a lead role in key climate questions within the research community. In 2012, one CO-OPS scientist, on detail working with the Pacific Regional Climate Service Director, helped to organize and execute a consensus building technical workshop for projecting sea level rise and coastal inundation in the Pacific Islands in partnership with the NOAA Coastal Storms Program. CO-OPS personnel are also very active in national and international conferences on sea level and climate change, providing papers, presentations, and posters, and engaging the climate community in discussion. We have also worked with the National Science Teachers Association to develop educational modules on various elements of physical oceanography, including sea level change.

Additionally, CO-OPS is very involved in activities through NOAA's Coastal Resilience Objective, as defined in the Next Generation Strategic Plan. Through this objective, CO-OPS has been working with other NOS offices to document protocols necessary for establishing NOAA Trust Resources as "sentinel sites for climate change impacts," one component of NOAA's emerging Sentinel Sites Program. This includes determining which areas require additional sea level monitoring, and how to tie sea level stations to geodetic infrastructure, to establish a complete picture of local land/sea interactions and local coastal processes in the face of climate change. Through this effort, we have also been working with the National Estuarine Research Reserve's Coastal Training Program and NOAA's Coastal Services Center (CSC) to inform sea level training and education activities. We worked with CSC and partner agencies on a new sea level rise visualization tool for the Gulf Coast, and are working with CSC and the National Weather Service to improve protocols for coastal flood warnings by integrating CO-OPS' statistical inundation analysis with CO-OPS sea level trends. We have also worked with a number of internal and external partners to provide guidance on utilization of CO-OPS sea level trends in conjunction with sea level projections for various coastal applications, including habitat restoration, coastal engineering, and land acquisition and planning. We have specifically been supporting the U.S. Army Corps of Engineers with their development of formal engineering guidance for including sea level change in project planning and design.

Finally, in response identified needs in NOAA's sea level assessment, completed in 2009, CO-OPS worked with NOAA's National Geodetic Survey, Office of Coast Survey, and Coastal Services Center to publish a document, "Technical Considerations for Use of Geospatial Data in Sea Level Change Mapping and Assessment." This document was published in FY11, and is being incorporated into key NOAA websites and trainings, including *Sea Levels Online* and *Digital* Coast, as well as the Climate Portal. In FY11, we held training sessions on tidal and geodetic datums, which incorporated sea level and climate change in the context of coastal decision-making. We also wrote an accompanying document to the technical considerations document, providing a step-by-step guide for incorporating sea level into planning, which is currently in press.

4. Publications and Reports

4.1. Publications by Principal Investigators

The following publications were completed in the last Fiscal Year, and include one or more of the project PIs. (*Note: The final reference is older, but is a critical reference for the relevant publications listed below.*)

NOAA National Ocean Service. 2010. *Technical Considerations for Use of Geospatial Data in Sea Level Change Mapping and Assessment.* Silver Spring, MD. NOAA Technical Report NOS 2010-01. http://tidesandcurrents.noaa.gov/publications/tech_rpt_57.pdf

Sweet, W.V. and C. Zervas, 2011. *Cool-Season Sea Level Anomalies and Storm Surges along the US East Coast: Climatology and Comparison with the 2009/10 El Nino.* Monthly Weather Review 2290-2299. DOI: 10.1175/MWR-D-10-05043.1.

Tebaldi, C.; Strauss, B. and C. Zervas, 2012. *Modeling Sea Level Rise Impacts on Storm Surges Along US Coasts.* Environmental Research Letters. *In press.*

Zervas, C. 2009. *Sea Level Variations of the United States; 1854-2006*. NOAA Technical Report, NOS CO-OPS 053. Silver Spring, MD.
http://tidesandcurrents.noaa.gov/publications/Tech_rpt_53.pdf

4.2. Other Relevant Publications

The sea level trends published by Zervas in the above publication are referenced broadly in publications. Of note this year is the work underway by the U.S. Army Corps of Engineers to update their engineering guidance:
http://www.iwr.usace.army.mil/index.php?option=com_content&view=article&id=813:usace-updates-sea-level-change-guidance&catid=72:news-2011

The U.S. Army Corps of Engineers (USACE), the primary agency responsible for coastal engineering projects in the US has recognized the potential for changing sea levels to impact the planning and design of coastal projects. The first guidance was issued in 1986 followed by the publication of the 1987 National Research Council study "Responding to Changes in Sea Level: Engineering Implications." (NRC, 1987) The most recent update to the sea-level change (SLC) guidance was in 2009 in the form of an Engineer Circular (EC) 1165-2-211, "Incorporating Sea-Level Change Considerations in Civil Works Programs." (USACE, 2009a, updated to EC 1165-2-212 in 2011) The 2009 guidance was developed with sea-level science experts at NOAA's National Ocean Service and the U.S. Geological Survey. The USACE goal is to develop practical, nationally consistent, legally justifiable, and cost effective measures, both structural and nonstructural, to reduce vulnerabilities and improve the resilience of our water resources infrastructure to changes associated with rising global sea level.

The USACE is currently developing implementation guidance in the form of a Civil Works Technical Letter (CWTL) that outlines the recommended planning and engineering approach at the regional and project level for addressing impacts of projected sea level change at Corps of Engineers projects. All of the primary mission areas of the Corps are being addressed, with emphasis on navigation, flood risk management, coastal storm damage reduction, and ecosystems. The guidance development is utilizing an interdisciplinary team that includes representatives from all the different regions of the USACE as well as from other key federal agencies dealing with infrastructure and systems. Representatives include numerous agencies, including the National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), Federal Emergency Management Agency (FEMA), U.S. Coast Guard, U.S. Naval Academy, Federal Highway Administration, Bureau of Reclamation, National Park Service (NPS), and the U.S. Navy. Personnel from the University of Southampton (UK), HR Wallingford (UK), and Moffatt & Nichol are also participating.

The 2009 EC directs the formulation and evaluation of project alternatives using low, intermediate, and high rates of future SLC for both the "with" and "without" project conditions. The existing trends computed by NOAA at long-term tide stations as part of this project are used as the baseline "low" rate for projects in the vicinity of the station. Various climate models are used for the out-year projections.

Additional publications which reference Zervas' sea level trends: (Note: Not a comprehensive list.)

Burgette, Reed J.; Ray J. Weldon II; David A. Schmidt. 2009. *Interseismic uplift rates for western Oregon and along-strike variation in locking on the Cascadia subduction zone*. Journal of Geophysical Research, Volume 114, B01408, 24pp., 2009. Doi: 10.1029/2008JB005679. http://www.agu.org/pubs/crossref/2009/2008JB005679.shtml

Bushek, David; Tracy Elsey Quirk; and Kurt Philipp. 2010. *Delaware Estuary Climate Ready Estuary Pilot: Vulnerability Assessment and Adaptation Planning Tidal Wetlands Case Study*. Appendix F. http://www.delawareestuary.org/pdf/Climate/CRE%20Appendix%20F%20-%20Tidal%20Wetlands%20Report.pdf

Chanton, Jeffrey. 2002. *Global Warning & Rising Oceans*. American Institute of Biological Sciences. http://universal-salvage.org.uk/pdf/WarmingRisingOceans.pdf

EPA. 2010. *Climate Change Indicators*, EPA 430-10-007, Environmental Protection Agency, Washington, DC, April 2010. http://www.epa.gov/climatechange/indicators/pdfs/ClimateIndicators_full.pdf

EPA. 2010. *Report on the Environment: Sea Level*. http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewMeta&ch=50&lShowInd=0&subtop=315&lv=list.listByChapter&r=216636

Foyle, Anthony M.; Vernon J. Henry; and Clark R. Alexander. *Georgia-South Carolina Coastal Erosion Study: Phase 2 Southern Region: State of Knowledge Report and Semi-Annotated Bibliography*.
http://www.skio.usg.edu/publications/downloads/pdfs/technical/gasc_coastalerosion_sok.pdf

Franck, Travis Read. 2009. *Coastal communities and climate change: a dynamic model of risk perception, storms, and adaptation*. Massachusetts Institute of Technology (student thesis). http://hdl.handle.net/1721.1/54846

Gibeaut, James C.; Eleonor Barraza, and Boris Radosavljevic. 2010. *Estuarine Wetland Habitat Transition Induced by Relative Sea-Level Rise on Mustang and North Padre Islands, Texas: Phase 1*. Prepared for Coastal Bend Bays and Estuaries Program. Publication CBBEP-64, Project Number-0822, July 2010. http://cbbep.org/publications/virtuallibrary/0822.pdf

Grape, Laura. 2009. *Building Resilience to Sea-Level Rise in Northern Virginia*. From Green Cities: New Approaches to Confronting Climate Change. OECD Workshop Proceedings. http://www.oecd.org/dataoecd/46/33/45377963.pdf#page=272

Gray, George, et. al. 2008. *Scientific Assessment of the Effects of Global Change on the United States: A Report of the Committee on Environment and Natural Resources National Science and Technology Council*.
http://books.google.com/books?hl=en&lr=&id=exSRYgA8tWEC&oi=fnd&pg=PR2&ots=jDCaiA09gU&sig=51aAjB0noVXrG3XprRaX6GgYTx4#v=onepage&q&f=false

Heberger, Matthew, et. al. 2009. *The Impacts of Sea-Level Rise on the California Coast*. California Climate Change Center.
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.170.9995&rep=rep1&type=pdf

Himmelstoss, Emily A.; Duncan M. FitzGerald; Peter S. Rosen; James R. Allen. 2006. *Bluff Evolution along Coastal Drumlins: Boston Harbor Islands, Massachusetts.* Journal of Coastal Research: Volume 22, Issue 5: pp. 1230 – 1240. http://www.jcronline.org/doi/abs/10.2112/06A-0005.1

Morton, Robert A. and Julie C. Bernier. 2010. *Recent Subsidence-Rate Reductions in the Mississippi Delta and Their Geological Implications.* Journal of Coastal Research: Volume 26, Issue 3: pp. 555 – 561.
http://www.jcronline.org.pinnacle.allenpress.com/doi/abs/10.2112/JCOASTRES-D-09-00014R1.1?journalCode=coas

Pendleton, Elizabeth A.; E. Robert Thieler; S. Jeffress Williams. 2010. *Importance of Coastal Change Variables in Determining Vulnerability to Sea-and Lake-Level Change*. Journal of Coastal Research: Volume 26, Issue 1: pp. 176 – 183.
http://www.jcronline.org.pinnacle.allenpress.com/doi/full/10.2112/08-1102.1

Reinhardt, Heiko; Dimitry Sidorenko; Manfred Wenzel; and Jens Schröter. 2010. *Sea Level Rise in North Atlantic Derived from Gap Filled Tide Gauge Stations of the PSMSL Data Set*. System

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Rosati, J.D. and Kraus, Nicholas C. 2009. *Sea level rise and consequences for navigable coastal inlets*. Shore and Beach, Volume 77, Number 4. Fall 2009. http://www.dtic.mil/cgi-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA508705

Sommerfield, Christopher K., Homa J. Lee, and William R. Normak. 2009. *Postglacial sedimentary record of the Southern California continental shelf and slope, Point Conception to Dana Point*. The Geological Society of America, Special Paper 454. http://books.google.com/books?hl=en&lr=&id=YwctFDH07bcC&oi=fnd&pg=PA89&dq=%22sea+levels+online%22&ots=dz46IO8Rar&sig=9lKkZx8yzEuTVg2sO-dJx7oFTqM#

Stauble, Donald K. 2008. *Coastal Engineering Project Impact Assessment Using Long-Term Morphodynamic Change Analysis*. FSBPA Conference Proceedings. http://www.fsbpa.com/08Proceedings/02Stauble2008.pdf

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Tronvig, Kristen A., et. al. 2003. *A Critical Need for Water Level and Datum Information in the Northern Gulf of Mexico*. THSOA Conference Proceedings. http://www.thsoa.org/hy03/3a_2.pdf

USACE. 2009. *Water Resources Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs*, EC1165-2-11, Department of the Army, U.S. Army Corps of Engineers, Washington, DC, 1 July 2009.

Wu, Shuang-Ye; Raymond Najjar; and John Siewert. 2009. *Potential impacts of sea level rise on the Mid- and Upper-Atlantic Region of the United States*. Climatic Change, Volume 95, Numbers 1-2, 121-138, DOI: 10.1007/s10584-008-9522-x. http://www.springerlink.com/content/yv3600446l4873n2/